BIO-FUELS FROM LOW-TEMPERATURE MICROWAVE AND CONVENTIONAL PYROLYSIS OF SEWAGE

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ABSTRACT

The use of microwave pyrolysis as an alternative for sewage sludge reutilization was investigated. This paper evaluates the basic chemical characteristic of the bio-fuel obtained in low-temperature microwave pyrolysis in comparison to that of the conventional pyrolysis. In this study, sewage sludge was dried and pyrolyzed in a single process at laboratory scale. Sewage sludge was placed in a quartz reactor, which in turn was placed in a microwave cavity oven. Graphite was used as microwave absorber. The pyrolysis temperature was moderate (at 650 °C) with five minutes heating. Conventional pyrolysis of sewage sludge by using fluidized bed reactor at similar temperature but lower heating rate was conducted for comparative purpose. It is found that microwave pyrolysis of sewage sludge at 650 °C gives rise to formation of 27.7% carbonaceous residue (char), 5.6% pyrolytic oil and 66.7% non-condensable gases (dry basis). On the other hand, 47.3% of char, 14.2% of oil and 39% of non-condensable gases were produced in conventional pyrolysis. Microwave and conventional pyrolysis of sewage sludge at moderate temperature yield pyrolytic oils with calorific values of 28852 and 37194 kJ/kg respectively, which is higher than that of lignite and sub-bituminous coal (23200 kJ/kg) thereby reflecting the potential of this fraction as fuel material.

Keywords: Sewage sludge, Pyrolysis, Low-temperature, Microwave, Fluidized bed, Bio-fuel

INTRODUCTION

In Malaysia, approximately 4.3 million m^3 of sewage sludge is produced in 2005 (Bernama, 2006). This sludge volume is expected to rise to 7 million m^3 by year 2020 (Ahmadun and Alam, 2002). Handling this waste is not easy and without doubt gives rise to some collateral pollution. Present practice in Malaysia is either to co-dispose it with solid waste at landfill sites or direct disposal in shallow trenches (Ahmadun and Alam, 2002). However, disposal by land filling and trenches require a lot of space and the soil has to be sealed adequately to prevent leaching of harmful compounds (Inguanzo *et al.*, 2002). Therefore, the country has to adopt a more practical, economic and acceptable approach in managing and disposing sewage sludge.

Building sludge lagoons that will serve as sludge holding and treatment facilities (Bernama, 2006) will provide a short-term solution in urban areas. For long term use, sludge settling tanks and digestors are required (Bernama, 2006). Another alternative process proposed for reutilization of sludge is pyrolysis. Pyrolysis is formally defined as chemical decomposition of organic materials by heat, in the absence of oxygen (Krietmeyer and Gardner, 1996). Occurs at a temperature range of 250 to 1000 ºC (Menendez *et al.*, 2002; Shinogi and Kanri, 2002), pyrolysis transforms organic materials into gaseous components and a solid residue containing fixed carbon and ash (Krietmeyer and Gardner, 1996). Upon cooling, pyrolysis of organic matter yield high energy, dense liquid fuel, which can be upgraded into alternative fuels (Sensoz and Kaynar, 2006).

In this study, microwave pyrolysis of sewage sludge is proposed as an alternative process for sewage sludge disposal and reuse. For comparative purpose, fluidized bed pyrolysis of sewage (representing the conventional pyrolysis system) was also conducted. Fluidization will not be discussed in detail because the intention of using fluidized bed reactor in the conventional pyrolysis system was to provide good mixing and uniform heating in the sample.

Until now, studies on microwave pyrolysis of sewage sludge were mainly focused at high temperature (1000 °C), using modified microwave oven with input power of 1000 W, in favour to higher production of fuel gases (Dominguez *et al.,* 2003; Dominguez *et al.,* 2005; Inguanzo *et al.*, 2002; Menendez *et al.,* 2004). The present study provides information on microwave pyrolysis of sewage sludge at low temperature (650 °C), using a modified microwave oven with lower input power (700 W). A modified household microwave oven with an input power of 700 W and microwave frequency of 2.45 GHz was used to perform the pyrolysis of sewage sludge at moderate temperature.

EXPERIMENTAL

Material

The dewatered oxidation pond sewage sludge used as the starting material for this study was taken from wastewater treatment plant at Taman Tun Dr. Ismail, Kuala Lumpur. The sludge, which has undergone aerobic digestion, had a moisture content of about 80% an ash content of 30.2% (dry basis). Details on the chemical characteristics of the sewage sludge are summarized in Table 1.

Table 1: Ultimate analysis of sewage sludge and pyrolytic oil (650 °C)

	Carbon (wt%)	Hydrogen (wt%)	Nitrogen (wt%)	Sulphur (wt%)	Oxygen[c] (wt%)	H/C	H/O
Sludge	33.79	5.35	5.74	0.93	54.19	1.89	1.57
M-Oil	52.52	6.57	1.27	0.56	39.09	1.48	3.88
F-Oil	76.85	9.55	3.31	1.12	9.71	1.48	16.53

c: calculated by difference

For microwave pyrolysis, wet sewage sludge blended with pure graphite was used as the feed material. Sewage sludge is poor microwave energy receptor (Dominguez *et al.,* 2003; Dominguez *et al.,* 2005; Inguanzo *et al.*, 2002; Menendez *et al.,* 2004), while graphite is easily heated by microwave energy (Committee on Microwave Processing of Material, 1994). Therefore, microwave pyrolysis of the sewage sludge sample is achievable by adding graphite as a microwave energy absorber in the sludge sample. Powder form of graphite was used since it is easily available, gives rise to good heat absorption due to its high surface area/volume ratio, and it provides a uniform heating process. For fluidized bed pyrolysis, pre-dried sewage sludge was ground into and sieved to particle sizes of 0-150 μm prior to its use.

Pyrolysis

In microwave pyrolysis study, sewage sludge was dried and pyrolyzed in a single process at laboratory scale. Sewage sludge was placed in a quartz reactor, which in turn was placed in a microwave cavity oven. The input power of the microwave equipment was set at 700 W and the microwave frequency used was 2.45 MHz. An infra red thermometer was used for monitoring the bed temperature. Helium was used to create an inert atmosphere in the reactor.

In fluidized bed pyrolysis, prepared sample was placed into a fluidized bed reactor with 20 mm internal diameter x 400 mm high, constructed of stainless steel with full gas flow and temperature control. Type K thermocouple was used for monitoring the fluidized bed temperature.

For both experiments, the purge gas outlet located above the heated zone was connected to a series of condenser filled with dichloromethane. The cooling medium for the condenser is tap water. The other end of the condenser was connected to the Tedlar ® gas bag. The gas bag was analyzed by using GC-TCD immediately after the experiment ended.

RESULTS AND DISCUSSION

Figure 1 illustrates the relationship between the oil yield percentage and the bed temperature during the fluidized bed and microwave pyrolysis of the sewage sludge. For both systems, the oil yield increase with the increasing temperature. The oil yield in the fluidized bed system continuously increased until it reached the maximum yield at 550 °C. At temperatures higher than 600 °C, oil yield is observed to drop due to most of the carboxylic and phenolic bonds in the sludge have been broken (Shen and Zhang, 2003). The decrease is also known as the result of secondary cracking in the sample during pyrolysis in fluidized bed, where low heating rate and longer treatment time were introduced (Dominguez *et al*., 2003).

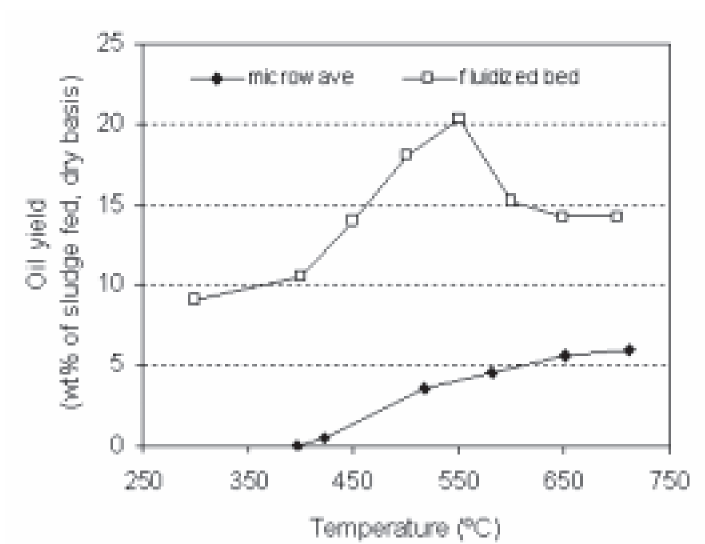

Figure 1: Yield percentage of pyrolytic oil with respect to temperature in microwave and fluidized bed pyrolysis

On the other hand, the oil yield in microwave pyrolysis shows a steady increase throughout the experiment. This is because no secondary cracking occur in microwave pyrolysis due to high heating rate and short residence time applied. At lower temperature, the oil yield was very low. In contrast, oil was produced in fluidized bed pyrolysis even at lower pyrolysis temperature. The probable reason is most of the microwave energy is used to remove water from the high moisture sludge at lower temperature.

The ultimate analysis of the pyrolytic oil produced in the fluidized bed and microwave pyrolysis of sewage sludge at 650 °C in comparison to initial sludge are summarized in Table 1. The pyrolytic oils produced in both experiments have significantly lower oxygen content and higher H/O atomic ratios than the initial sludge. The severity of the thermal treatment gives rise to oils that become considerably deoxygenated than the initialsludge, indicating that a large number of functional groups must have been lost during the pyrolysis, especially when the fluidized bed was used (Dominguez *et al.*, 2006; Dominguez *et al.*, 2005).

The pyrolytic oil of the fluidized bed system has higher carbon and hydrogen content. The H/C ratios of the pyrolytic oils suggest the presence of compounds with a high aliphatic content (Dominguez *et al.*, 2005). Nevertheless, the H/C value is lower than those for the sludge, which indicates that aromatisation reactions must have occurred to some extent (Dominguez *et al.*, 2006). The sulphur content of both pyrolytic oils were higher than the maximum sulphur content limit permitted by the US EPA where only 0.05 wt% (500 ppm) of sulphur is permitted for non-road diesel fuel.

Figures 2 and 3 summarize the calorific value (CV) of the pyrolytic oil obtained in the microwave pyrolysis (M-oil) and fluidized bed pyrolysis (F-oil) in comparison to the CV of initial sludge sample and several types of liquid fuel. It is observed that the CV of the pyrolytic oil obtained in fluidized bed pyrolysis is higher than that of microwave oil.

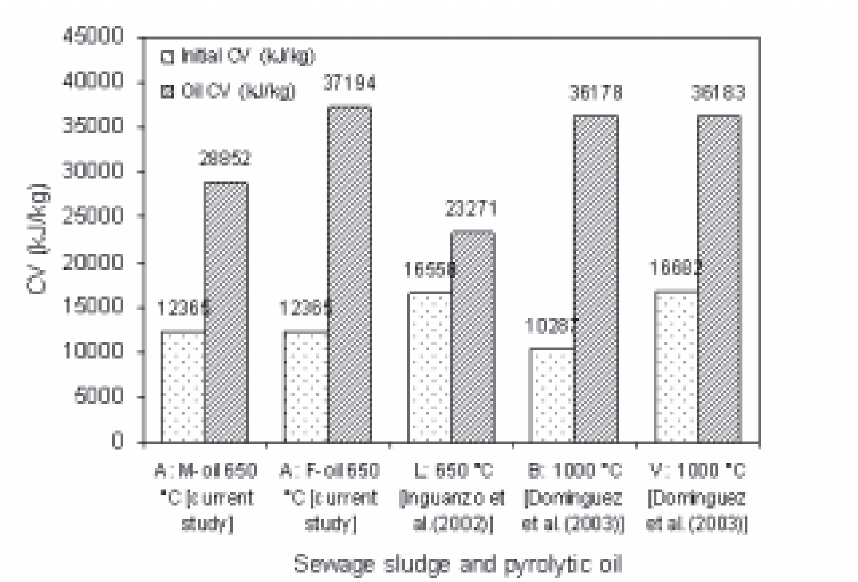

Figure 2: Calorific value for sludge sample and pyrolytic oil obtained in microwave and fluidized bed pyrolysis in present study (M-A and F-A) and that of Dominguez *et al.* (2003)

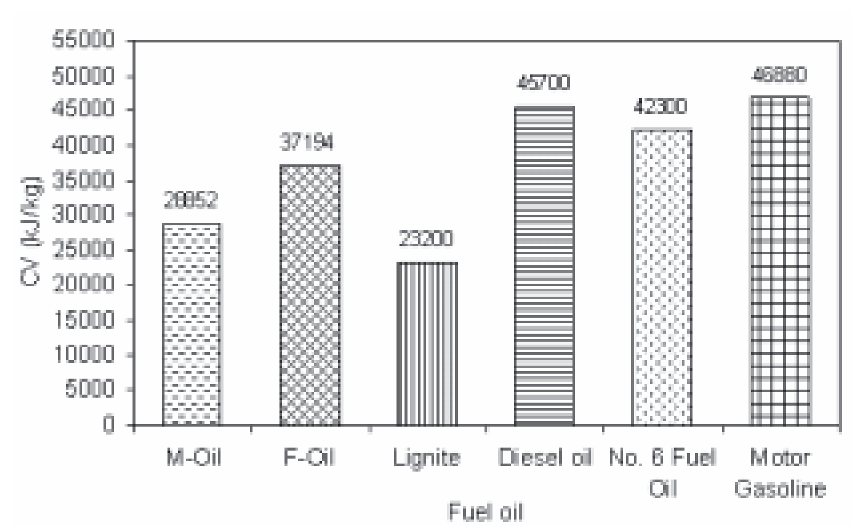

Figure 3: Calorific value of microwave and fluidized bed pyrolytic oils in comparison to several liquid fuels (Perry, 1997; Dominguez *et al.*, 2005; Gaur and Reed, 1998)

The CV of M-oil is somehow lower than M-B and M-V. These are pyrolytic oils produced by sewage sludge pyrolysis by using microwave oven with 1000 W input power (Dominguez *et al.*, 2005). During these treatments, maximum temperature reached was 1000 °C compared to lower temperature (650 °C) applied in present study. This may results in a lower devolatilization in the sludge sample during pyrolysis, and consequently lower CV was obtained in the oil yield.

In addition, compared to diesel oil and No. 6 fuel oil, M-oil has CV of only 63 to 68% of that for these fuels. In addition, compared to diesel oil and No. 6 fuel oil, the pyrolytic oil has CV of only 63 to 68% of that for these fuels. The CV of the resulting oil however, is higher than the 23200 kJ/kg energy content in lignite and sub-bituminous coal (Perry, 1997) thereby reflecting the potential of this fraction as a fuel. Besides being used as fuels, the oil may also be an important source of valuable chemical feedstock (Dominguez *et al*., 2003; Yaman, 2004).

The CV of the resulting oil was about 81 to 88% of the CV for diesel and No. 6 fuel oil respectively. However, the value is comparable to some pyrolytic oil obtained in previous study such as wood oil which CVs are between 33530 to 38020 kJ/kg (Gaur and Reed, 1998). The high CV of F-oil (37194 kJ/kg) reflects its potential for use as liquid fuel.

CONCLUSION

In conclusion, sewage sludge can be converted to bio-fuel when subjected to pyrolysis treatment. Microwave pyrolysis has a shorter processing time compared to the conventional one, and the drying and pyrolysis of sewage sludge can be conducted in a single step. However, conventional pyrolysis gives a higher oil yield compared to microwave pyrolysis. Both microwave and conventional pyrolysis processes give rise to the production of bio-fuel with calorific value of 28852 and 37194 kJ/kg respectively. The calorific values are higher than that of lignite and sub-bituminous coal thereby reflecting the potential of this fraction as fuel material.

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